

Understanding Impacts of Outflow on Tropical Cyclone Formation and Rapid Intensity and Structure Changes with Data Assimilation and High-resolution Numerical Simulations

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LONG-TERM GOALS

Understanding the processes that contribute to tropical cyclone (TC) formation, intensity and structure changes is essential for improving the predictability of TCs. Previous studies have focused mostly on the low- to mid-level processes leading to TC formation and rapid intensity and structure changes. The influence of upper-level atmospheric processes, especially the evolution of the outflow layer has not received much attention until recently. Therefore, the long-term goal of the proposed work is to improve our understanding and prediction of the tropical cyclone outflow layer, its evolution, and relation to tropical cyclone (TC) formation and intensity and structure changes.

OBJECTIVES

Using advanced data assimilation methods and state-of-the-art numerical models, the objective of this project is to investigate comprehensively several key issues that are identified in relation to TC outflow dynamics, processes, and evolution: 1) How does outflow layer evolve during the genesis and rapid intensification (RI) of a TC? What are their relationships to the TC rapid intensification (RI) and structure changes? 2) How does the outflow interact with inner-core convection and updrafts during RI? 3) How does TC outflow interact with environmental flows, especially large-scale troughs and ridges? How do these interactions impact TC RI and rapid decay (RD)? 4) To what extent can satellite data assimilation improve the predictability of TC outflow and related TC structure changes, RI and RD?

APPROACH

In order to achieve the research objectives of this proposal, we propose to conduct high-resolution numerical simulations by assimilating satellite, radar, and in-situ observations into the Weather Research and Forecasting (WRF) and/or the Coupled Ocean/Atmospheric Mesoscale Prediction System (COAMPS[®]) mesoscale models using ensemble Kalman filter (EnKF) data assimilation methods to obtain the best possible high-resolution analysis and numerical simulations. Specifically,

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available in-situ observations, satellite and radar data during recent field programs (such as ONR TCS08 and NASA HS3) will be assimilated. In addition, leveraged by the results from the proposed questions and high-resolution data assimilation, we will evaluate the Naval Research Laboratory (NRL)'s new generation global model, the Navy Global Environmental Model (NAVGEM), for its ability to predict atmospheric conditions in outflow layers.

People involved in this project in FY13 include the PI (Prof. Zhaoxia Pu) and one of her graduate students.

WORK IN PROGRESS

Since the project started in May 2013, work progress has been made in the following areas to examine the effect of upper-level atmosphere processes on TC formation:

- Examining the role of upper level atmosphere warming in TC genesis rapid intensification
- Investigating the effect of the accurate representation of the upper-level atmospheric processes on the predictability of TC genesis with data assimilation

RESULTS

(1) The role of upper level atmosphere warming in TC genesis and rapid intensification

In a previous study by Li and Pu (2013, *JGR* manuscript), the sensitivity of numerical simulations of the genesis of Typhoon Nuri (2008) to initial conditions was examined with the WRF model. Two sets of experiments were conducted using initial and boundary conditions derived from two different global analyses [NCEP Global Forecasting System final analysis (FNL) and ECMWF-interim reanalysis (ERA)]. The sensitivity of numerical simulations to different forecast leading times and physical parameterization schemes was also examined. Simulation results were compared with Doppler radar and aircraft dropsonde observations obtained during TCS-08. It was found that the initial and boundary conditions derived from one global analysis (e.g., FNL) failed to predict Nuri's genesis, whereas the initial and boundary conditions derived from the other global analysis (e.g., ERA) led to successful numerical simulations of the formation of Nuri.

Following this previous effort, the role of mid- to upper-level warming during Nuri's rapid intensification (RI) is examined. As shown in Figure 1, in the nondeveloping case (with FNL initial conditions), most warming occurred only in the middle level. In contrast, in the developing case (with ERA initial conditions), the middle to upper levels experienced significant warming due to diabatic heating during Nuri's genesis phase and also before and after Nuri's RI. Following Zhang and Zhu (GRL, 2012), the pressure drop was derived by integrating the hydrostatic equations using the temperature field. Results showed that the pressure drop derived from the temperature at all levels explained at least 90% of the pressure drop during the period (Figure 2). The same calculation that used the temperature above 650 mb showed that the pressure derived from the hydrostatic equation could explain 80% of the pressure drop during pre-genesis, genesis and early RI but 60% during the mature phases of Nuri (Figure 2). The strong indication here was that mid- to upper-level warming played a significant role in Nuri's formation and RI.

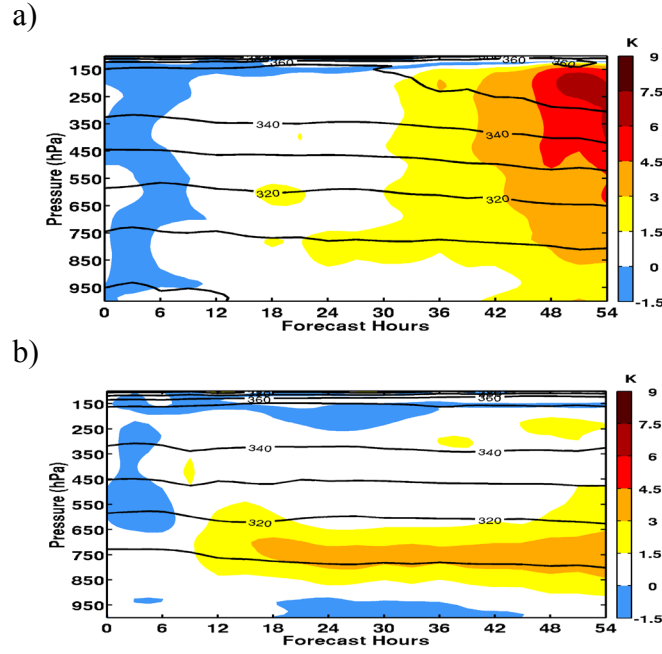


Figure 1: Time-height cross section of temperature changes (T' , shaded, unit: K), superposed with potential temperature (contoured at intervals of 10 K) at the circulation/eye center from the 54-h prediction (between 1800 UTC Aug 15 to 0000 UTC Aug 18, 2008) of Typhoon Nuri (2008) where T' are defined with respect to the (1000 km x1000 km) area-averaged temperatures at the model initial time. a). Simulation with initial and boundary conditions derived from ERA; b). Simulation with initial and boundary conditions derived from FNL. [Nuri's formation occurs at 24 h; RI occurs 30-54 h]

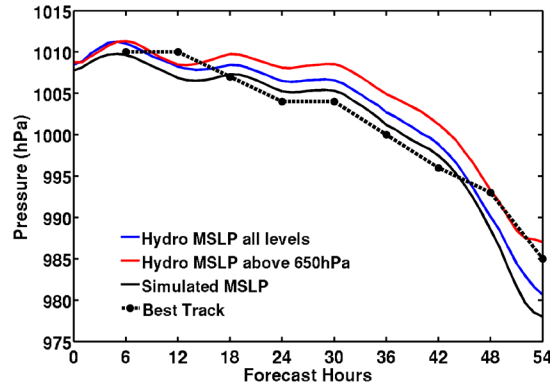


Figure 2: Time series of the JTWC best track (dash black) and simulated MSLP (solid black) using ERA initial and boundary conditions, and the hydrostatically estimated MSLP (blue) by including $dT(z, t) > 0$ in the 1000–150 hPa layer (blue) and in the 650-150hPa layer (red), respectively. [Nuri's formation occurs at 24 h; RI occurs 30-54 h]

In addition, in order to identify the environmental conditions that control TC genesis, a recent study was done to examine a new method to evaluate the precursors of TC genesis using high-resolution ensemble forecasting and relative operating characteristic diagram. With WRF model, high-resolution

ensemble forecasts are conducted in various configurations using a bred vector method to form a set of 140 ensemble members for predicting the genesis of Hurricane Ernesto (2006). This set of 140 ensemble members is employed to study the precursors of Hurricane Ernesto's genesis by contrasting the genesis and nongensis cases. It is found that the *upper-level warming*, along with moist conditions at 850 hPa, vertical wind shear, and the strength of the 850 hPa pre-existing wave play notable roles in Ernesto's genesis.

- (2) The impact of the accurate representation of the upper-level atmospheric processes on the predictability of TC genesis

In order to examine the accurate representation of the upper-level atmospheric processes on the predictability of TC genesis, we conducted a series of data assimilation and numerical simulation experiments with the aforementioned cases for Typhoon Nuri (2008). Specifically, we picked a set of experiments with FNL initial and boundary conditions that fails predicting Nuri's genesis as a control experiment. Then, we assimilated available satellite observations from NASA Atmospheric Infrared Sounder (AIRS) into the new set of experiments in the early phase of the numerical simulation. Preliminary results indicated that assimilation of AIRS derived temperature profiles results in more accurate prediction of Nuri's genesis, whereas without the AIRS data assimilation, the model fails predicting Nuri's genesis. More importantly, data assimilation results imply that the upper level warming contributes to Nuri's genesis. Assimilation of AIRS data enhances the representation of upper level (within and near the outflow layer) warming in the WRF model. Detailed diagnosis of the results and more case studies are in progress.

IMPACT/APPLICATIONS

The better understanding of the role of upper level atmosphere and TC outflow will lead to improvement in our ability to predict TC formation, rapid intensification and intensity and structure changes.

PUBLICATIONS

- [1] Thatcher, L. and Z. Pu, 2013: Evaluation of tropical cyclone genesis precursors with relative operating characteristics (ROC) in high resolution ensemble forecasts: Hurricane Ernesto. *Tropical Cyclone Research Review* (in press).
- [2] Li, Z. and Z. Pu, 2013: Sensitivity of numerical simulation of Typhoon Nuri to model resolution: implication for the role of upper-level warming in rapid intensification. To be submitted to *Mon. Wea. Rev.*